UNIVERSITY OF SUSSEX

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Positioning with opportunistic cellular signals

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Agenda

Internet of Things requirements for positioning

The interest in using opportunistic cellular signals

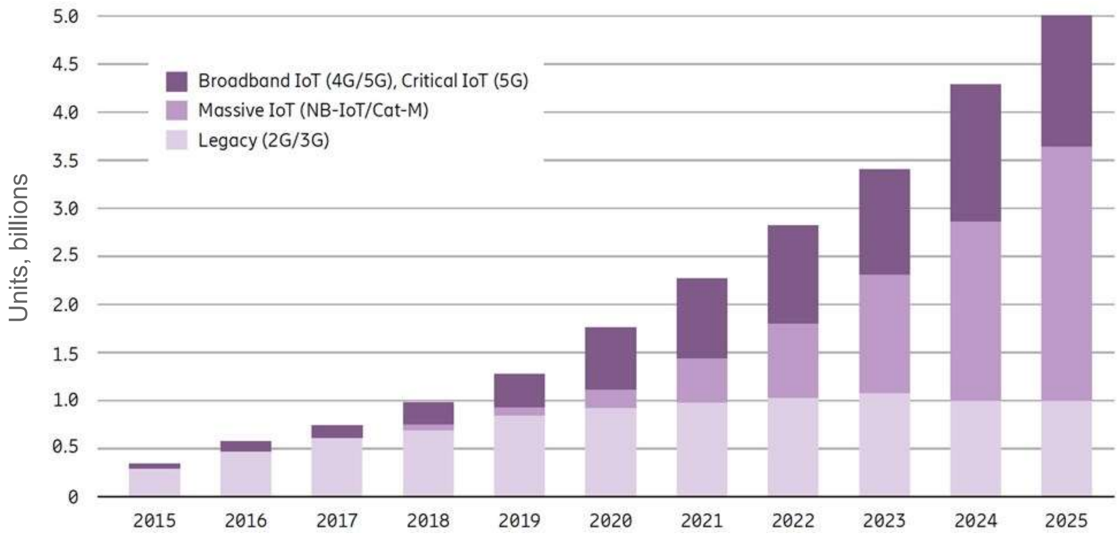
Experiences ranging with opportunistic cellular signals
- The base stations
- The measurements

Implications

Conclusion and references

The Internet of Things

A wide range of connected, mobile devices
- Lots of things, low cost, often battery powered
- Scattered about, connected by cellular wireless



Ericsson [1]

Positioning for the Internet of Things

Application usage

	Steering	Tracking	Sensing
Outdoors	Car navigation Autonomous vehicles Drones	Shipments Pets E-scooters	Refuse bins Parking meters Process control
Indoors	Personal navigation Fork lift trucks	People care Equipment hire Manufacturing	Vending machines Printers Utility meters

Positioning characteristics

Continuous Use by device, ≤1Hz	Updates Alerts to service	Occasional Time synchronisation
Reliability	Coverage	Low cost

May have additional infrastructure equipment for enhanced positioning in a local area

Cellular signals for positioning interesting as…

Signals strong
- Penetrate buildings
- Measurement may be low energy

Widely deployed
- Coverage provided over wide area
- Standardised and available worldwide

Good quality
- Bandwidth often 20MHz, so promising for accuracy and resolution in multipath
- Good quality, stable, maintained transmitters

Cellular connectivity
- So low marginal cost of adding positioning

Indoor positioning with LTE

Indoor experiment

Performance promising

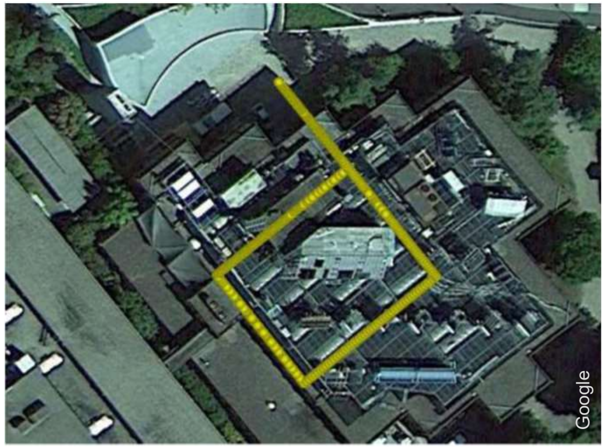
- 100% yield
- 10m 50% CEP accuracy

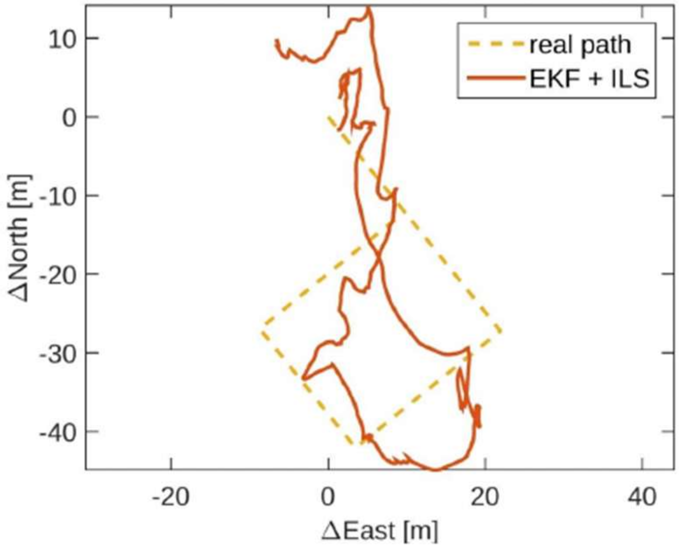
Number of base station signals receivable

Operator	#1	#2	#3	In all
Base stations	6	3	1	10
Measured	2	2	1	5

- Need ≥3 signals for ranging (2D and local time)
- Not sufficient signals from any one network
- Sufficient from all networks when used together

Rapperswil, CH, June 2015
LTE signals in 1.8GHz band
channel bandwidth 15-20MHz
2D+t position, Kalman Filter





u-blox [3]

Using opportunistic cellular signals for positioning

The special Positioning Reference Signal (PRS) not seen in these experiments

- This would cost capacity in the transmissions, and in the empty slots to improve their hearability
- Experiments use the Cell Specific Reference Signal (CRS), part of normal communications protocol

Experiments take steps to re-synchronise the timing of the base station signals

Opportunistic - have to live with network designed for connectivity, not for positioning

- Limited base stations from one network
  => use multiple networks
- Cost of positioning signals means they aren't used
  => use signals used for normal communication

The open questions of using opportunistic signals…

- Location of base stations producing the signals not known
- Timing of the base stations is not synchronised

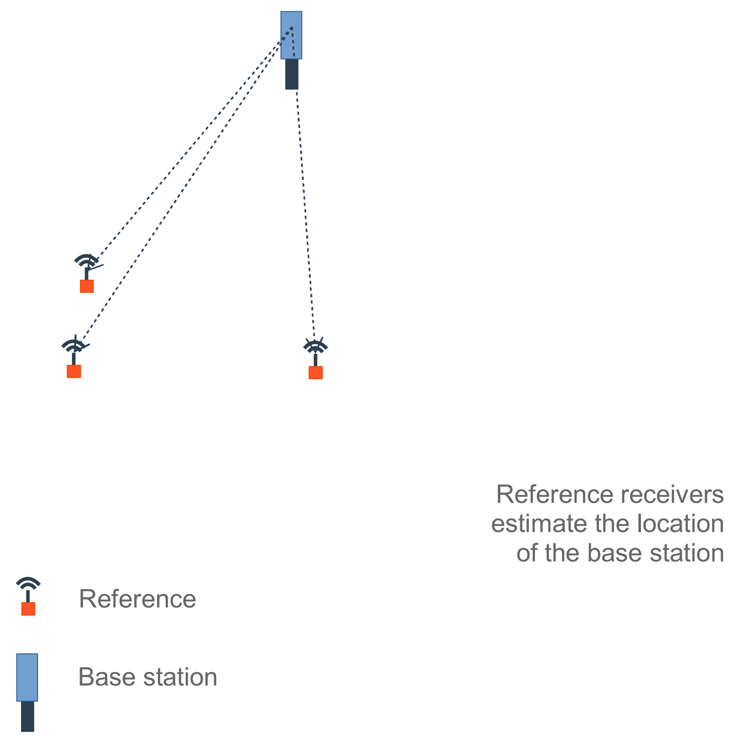
Estimating the locations of the base stations

A database
- Difficult if using multiple networks

A field survey
- Visual

Measurements with reference receivers
- Reverse trilateration from receivers in known locations (e.g. which have GNSS)

Simultaneous Localization and Mapping (SLAM)
- Learning the environment live from measurements by the target as it moves through the environment



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Which signal is coming from which base station?

Signals are named, for connectivity purposes

- Logical naming (Country, Network, Area, Cell)
- Physical naming (Frequency, colour Code)

Network configuration changes

- As network deployed and maintained
- Responding to traffic changes

Naming identities of base stations change

- Although coverage continues

Need to know the current cellular identity of each base station

- Although these may belong to different networks
- To match the signal up with the base station location

Coverage of a GSM cell, before (orange) and after (red) a cell renaming by the network

Udine University [5]

Estimating the relative timing of the signals

Known synchronisation of the base stations by the supplier

- Within a network, but may not be precise
- Very unlikely to have synchronisation between multiple networks

Concurrent timing measurements by a reference receiver

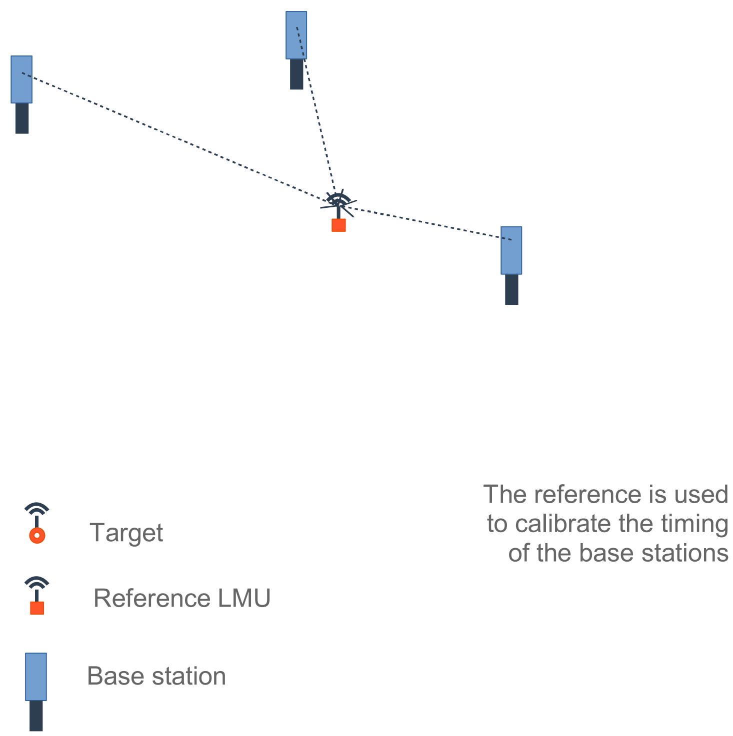
- Fixed Localization Measurement Unit (LMU)
- Mobile reference unit with GPS

Calibration as an initial condition

- Position known at the start of the route

A set of measurements in multiple locations

- Solving the equations (Matrix Solo)



University of California, Riverside [6] Cambridge Positioning Systems [7]

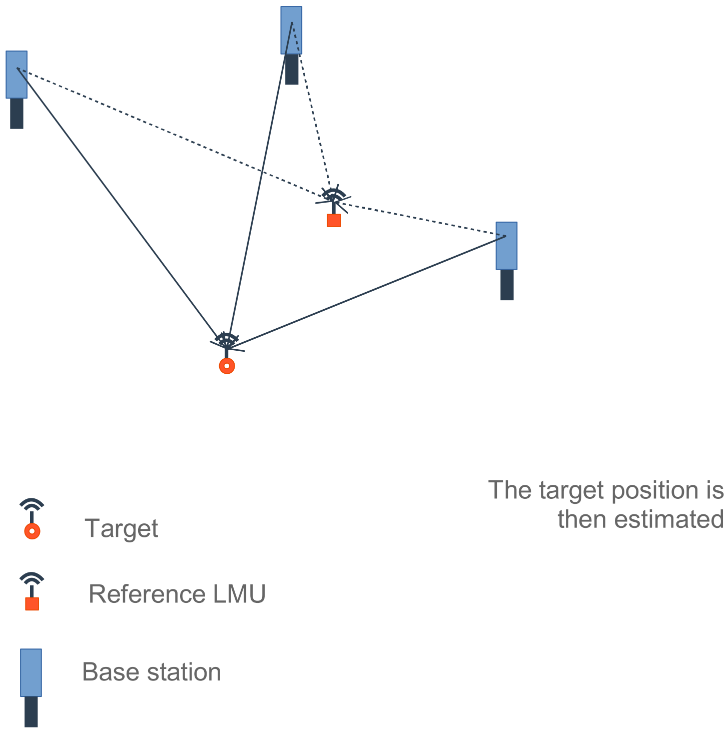
Can then estimate the target location

Estimate timing of the signals from the base stations
- E.g. with a reference receiver, as before

Measure the time of arrival of the signals at the target

Estimate the unknown target
- Location
- Its timing

Note – 2D location
- Base stations generally deployed horizontally, so vertical positioning is difficult

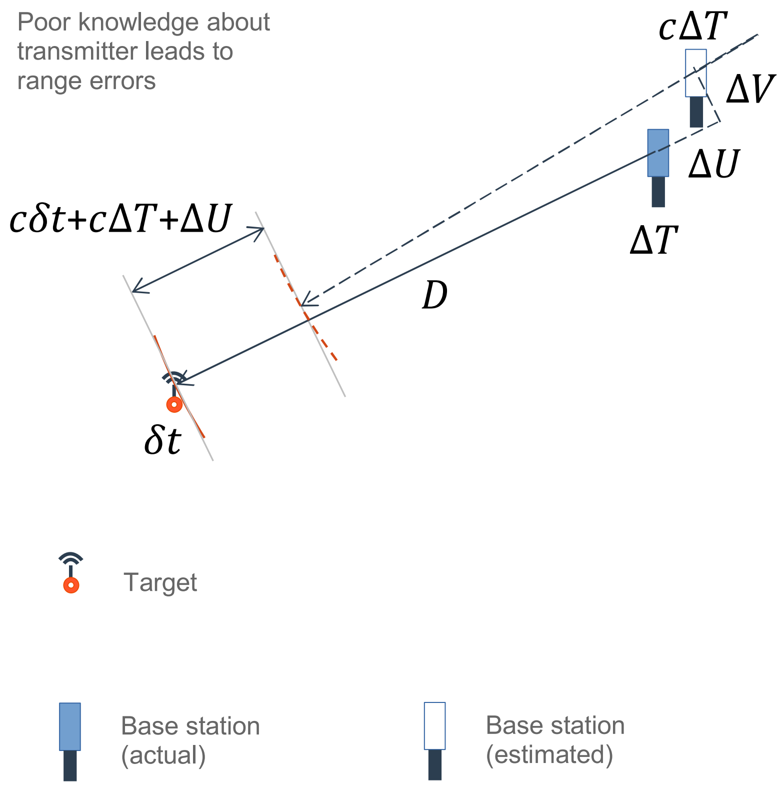


Effect of base station inaccuracies on positioning

Positioning with a distant source
- With synchronised timing
- To estimate the range in the direction of source

In-line error in pseudorange
- Error in estimation of source location ΔU
- Error in source timing (synchronization) cΔT
- Error in timing measurement by target $c\delta t$

Minor errors
- Small effect, depending on ratio $(\Delta V / D)$
- Second order effect from the curvature of the signal wavefront



Base station errors avoided by using a reference

Positioning with a distant source

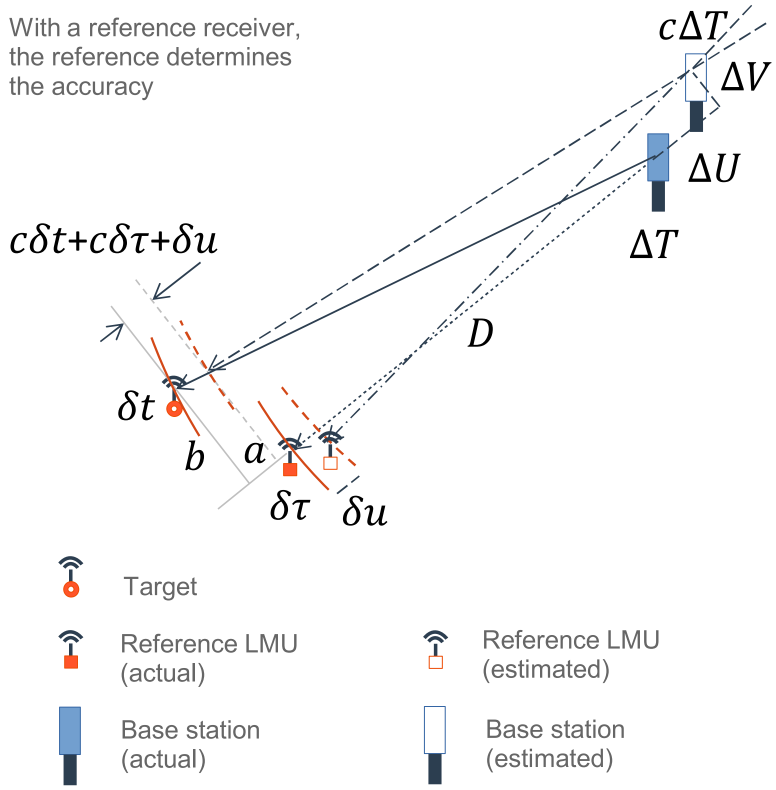
- With a reference receiver calibrating signal timing
- To estimate the range in the direction of source
- Relative to the location of the reference

In-line error in pseudorange

- In-line displacement and base station timing both have no effect on distance estimate as base station's timing anyway unknown, and pseudorange calibrated at the reference
- Instead have effect of errors in reference location δu and timing $c\delta\tau$
- Error in timing measurement by target $c\delta t$

Minor errors

- Small effect, depending on ratio $(\Delta V / D)$ and distance b of target from reference
- Second order effects from apparent curvature of the signal wavefront



What signal bandwidth to use?

Internet of Things devices 'low end'

- Optimised power consumption, link budget and cost for low data rate communications

3GPP provides for

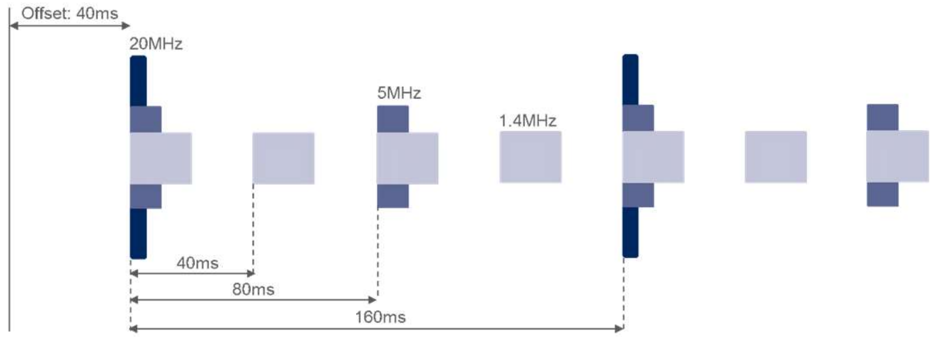
- Narrowband Positioning Reference Signals (1.4MHz)
- Aligned with the wider bandwidth positioning reference signals

For positioning indoors we want wider bandwidth

- For accuracy: Cramer Rao Bound, error limited by s/n and bandwidth

$$\sigma^2 \geq \frac{1}{2\left(\frac{\mathcal{E}_s}{N_0}\right)\beta^2}$$

- To separate multipath components



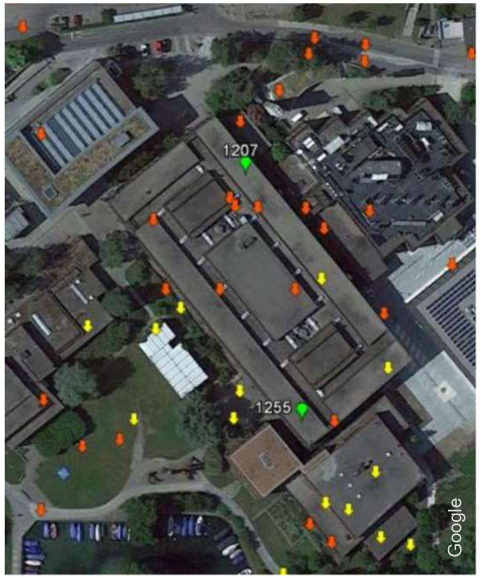
Rel 14 Narrowband Positioning References Signals aligned with full bandwidth LTE reference signals

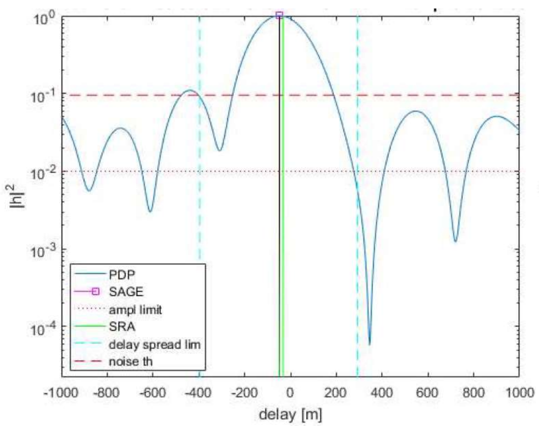
Choice of bandwidth

Experiment processing different bandwidths of the CRS (1.8GHz LTE) received indoors

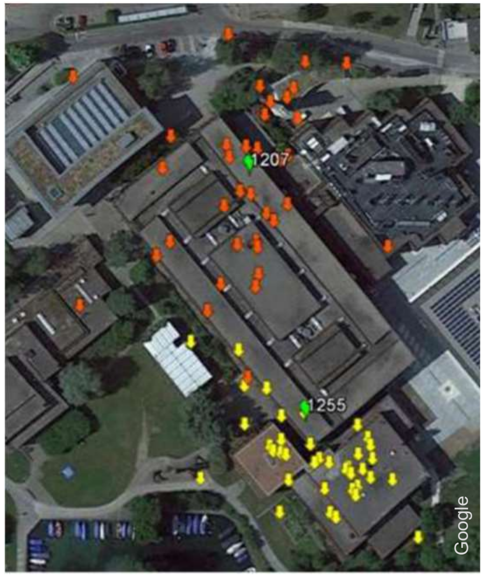
Beneficial to use measurement bandwidth ≥5MHz for positioning

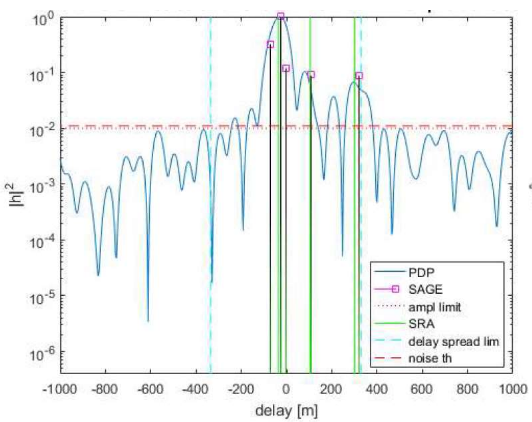
1.4MHz – 55m 50% CEP



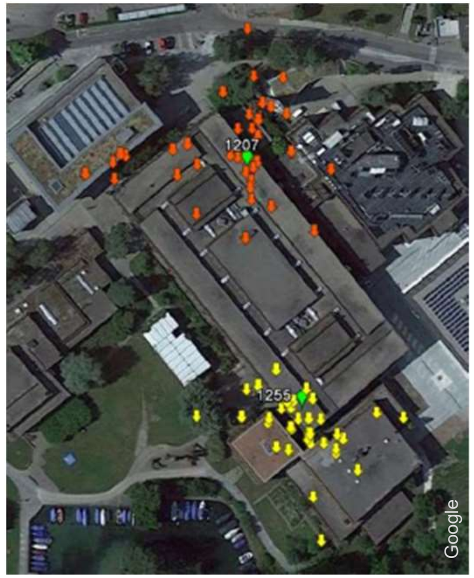


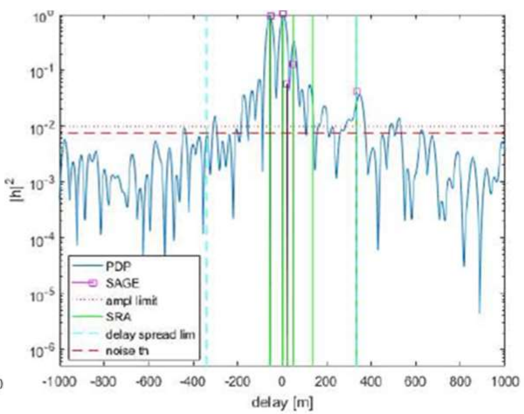
5MHz – 25m 50% CEP





10MHz – 15m 50% CEP





u-blox [3]

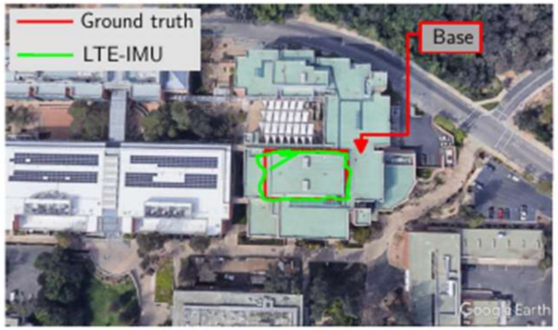
Carrier phase information for continuous tracking

Phase in common use for GNSS navigation
- Track carrier as well as modulation code

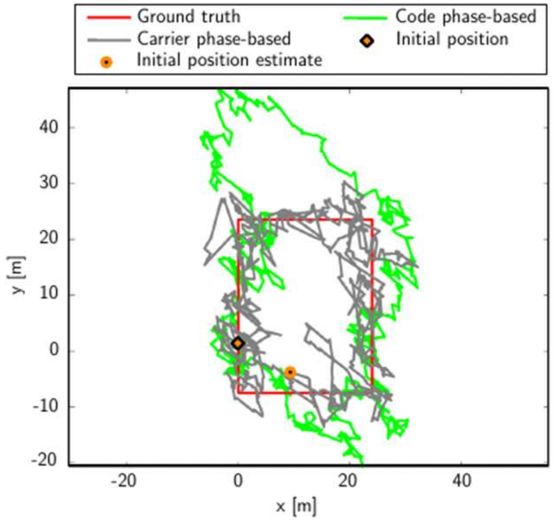
Phase provides additional information
- An additional measurement
- Carrier wavelength precision

But it has ambiguity
- Resolve with other information
- Tracking may be subject to cycle slip due to multipath

Indoor experiment with cellular carrier phase
- 11m RMSE for code phase (Time of Arrival)
- 5m RMSE for carrier phase
- Can use cellular phase information for navigation



University of California Riverside
LTE signals sampled at 20MHz
2D+t, Kalman Filter
Optionally combined with IMU



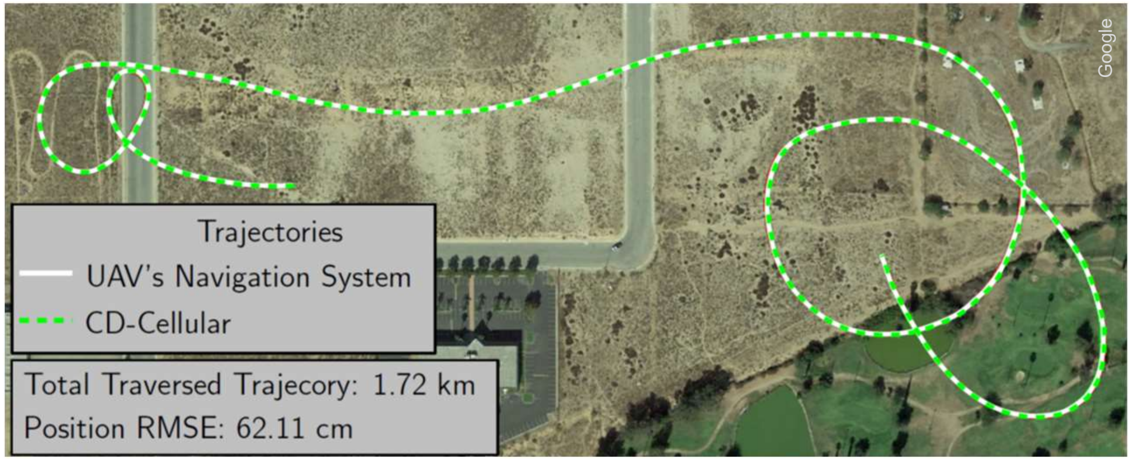
University of California, Irvine [9]

What’s the best you can do?

Tracking the position of a target drone, outdoors

With the reference provided by a second drone

Positioning accuracy <1m



Colton, California
Positioning with CDMA 883MHz,
carrier phase measurements at 37Hz
2D Kalman Filter

System implications

Measure signals of multiple communications networks, using the normal synchronisation signals

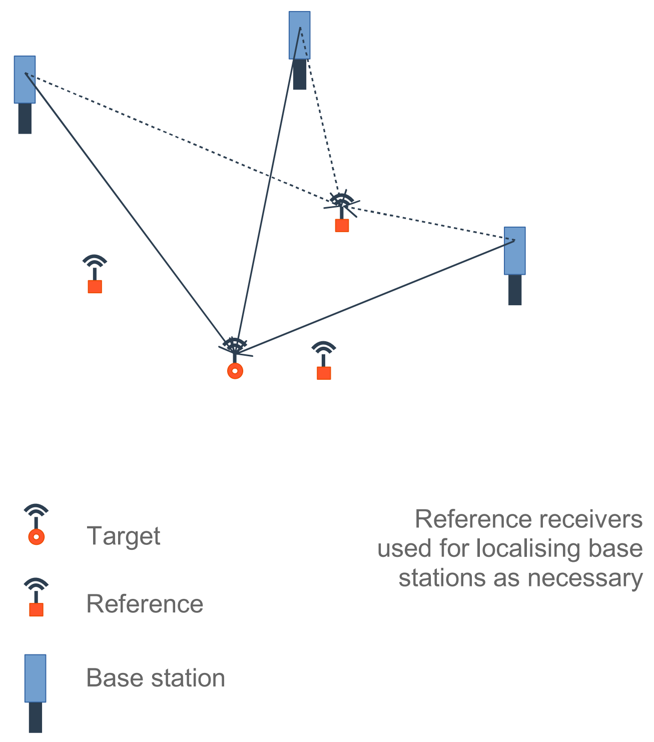
- To measure as many signals as possible
- While avoiding extra cost

Deploy reference receivers to calibrate timing

- (Simple local infrastructure)
- Allows unsynchronised base stations
- Reduces base station location accuracy requirements
- Use for localising signal sources

A service providing current cell ID information would be very helpful

- For keeping abreast with the network changes



Receiver implications

Should measure Time of Arrival of signals on multiple networks

- Don’t necessarily have to connect to the network measured
- Best efforts – no performance specification for opportunistic signal measurement
- Preferably against a stable local clock

Desirable to measure signals with ≥5MHz bandwidth for indoor positioning

Measure and track carrier phase (and doppler) for movement estimation

Limitations of using opportunistic cellular signals

Cannot guarantee signal availability and performance

- Availability and placement of sources is outside system control
- Base stations’ timing drift to some extent
- Signals may change without notice

Vertical positioning difficult

- Sources typically distributed horizontally

Some means and effort is required to characterize the signals in the locality

- Deployment of LMU reference receivers
- SLAM learning techniques by targets

When using cellular signals indoors have the limitations due to multipath propagation conditions

In conclusion

Cellular communication signals reach indoors, and their measurement provides useful information for positioning

- Time of arrival (with a bandwidth of ≥5MHz)
- Carrier phase

Opportunistic positioning with cellular signals has been demonstrated indoors and outdoors, using the existing cellular base station infrastructure

- Good indoor coverage and performance can be achieved by using signals from multiple network operators
- A local reference receiver can provide the calibration of the timing of the base station signals

Opportunistic cellular signals can make a useful contribution to positioning for the IoT applications of steering, tracking and sensing, at low marginal cost

- Complementary to measurements by GNSS, IMU, barometer

For further information

References

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9. “Performance Characterization of an Indoor Localization System with LTE Code and Carrier Phase Measurements and an IMU” Ali A Abdallah et al (U of California, Irvine) IPIN 2019

Contact welcome

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